Modelling overflow using mixed integer programming in short-term hydropower scheduling

Per Aaslid, SINTEF ER

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Teknologi for et bedre samfunn

Contributors

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- Dag Haugland, UiB – Professor, Main supervisor
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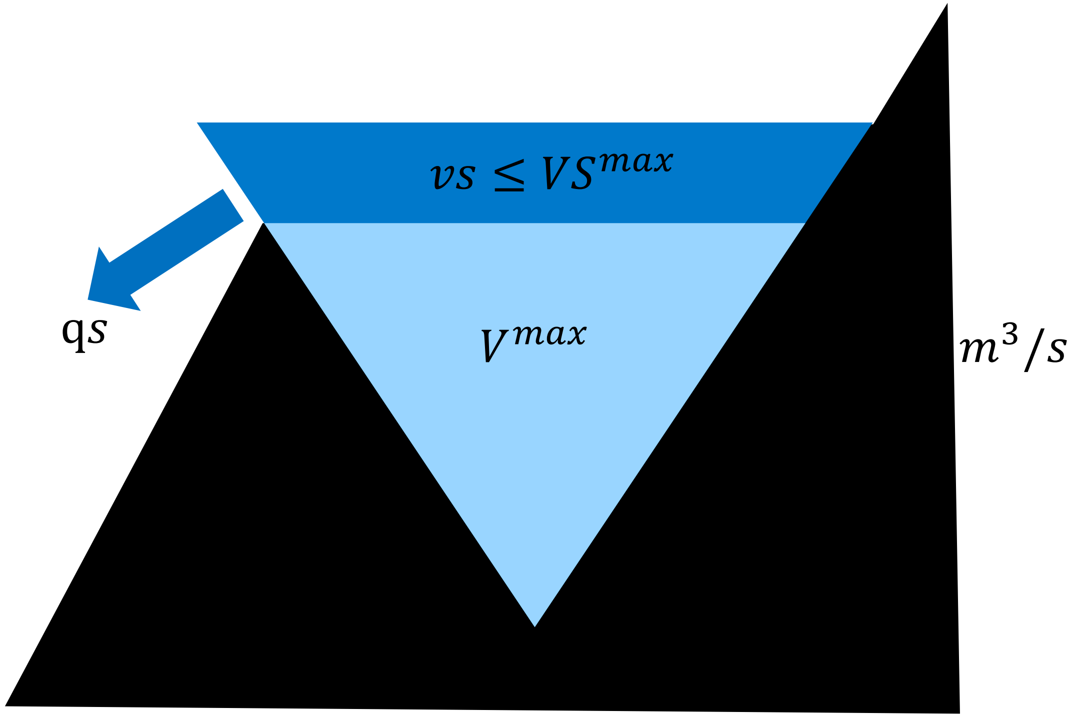
Outline

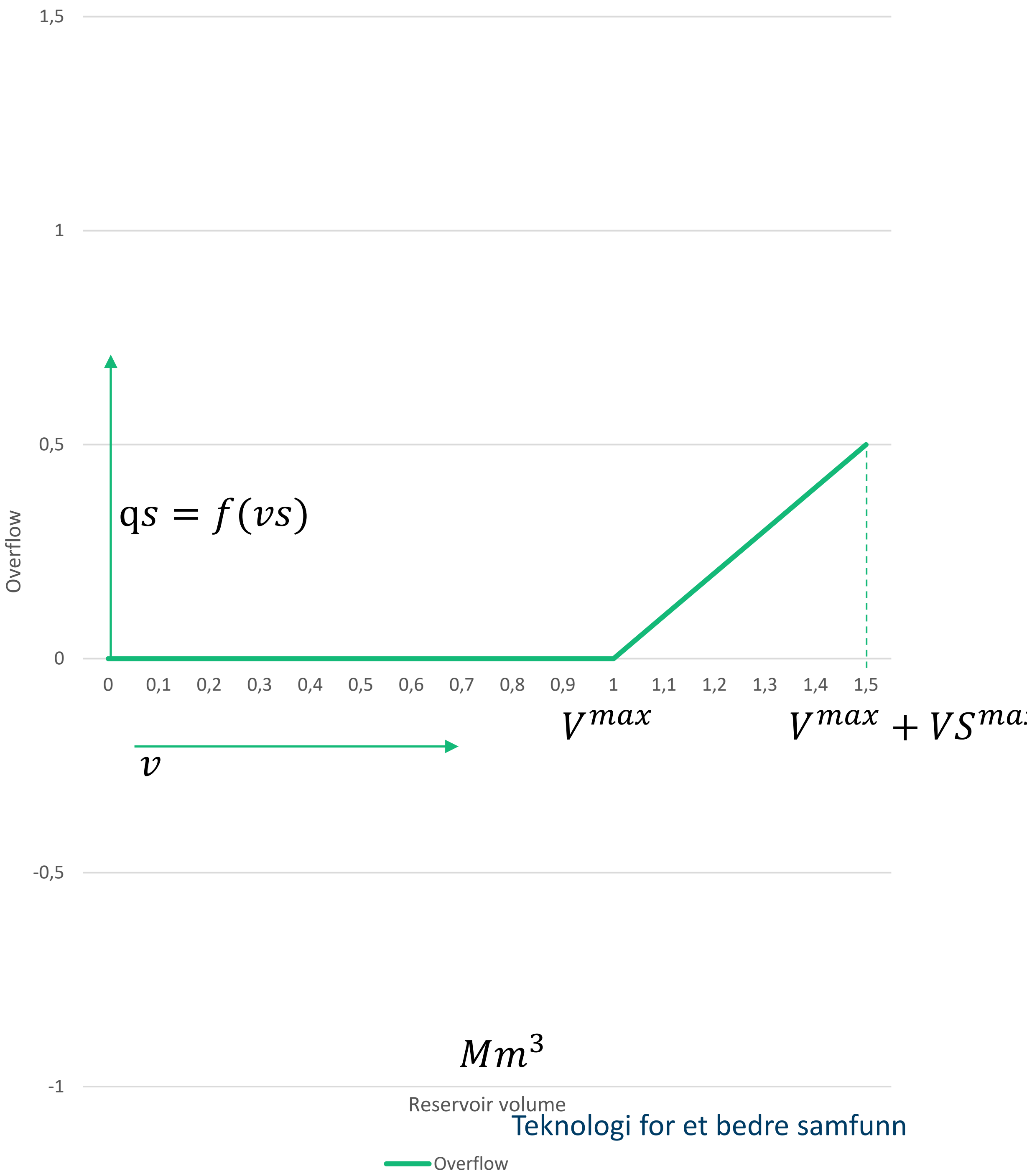
- Overflow modelling: LP vs MILP
- Challenges: non-physical overflow vs computation time
- Solutions
- Results

Overflow function



$$vs = \max(0, v - V^{max})$$

Non-convex



Mathematical formulation

$$vs \geq 0$$

$$vs \geq v - V^{max}$$

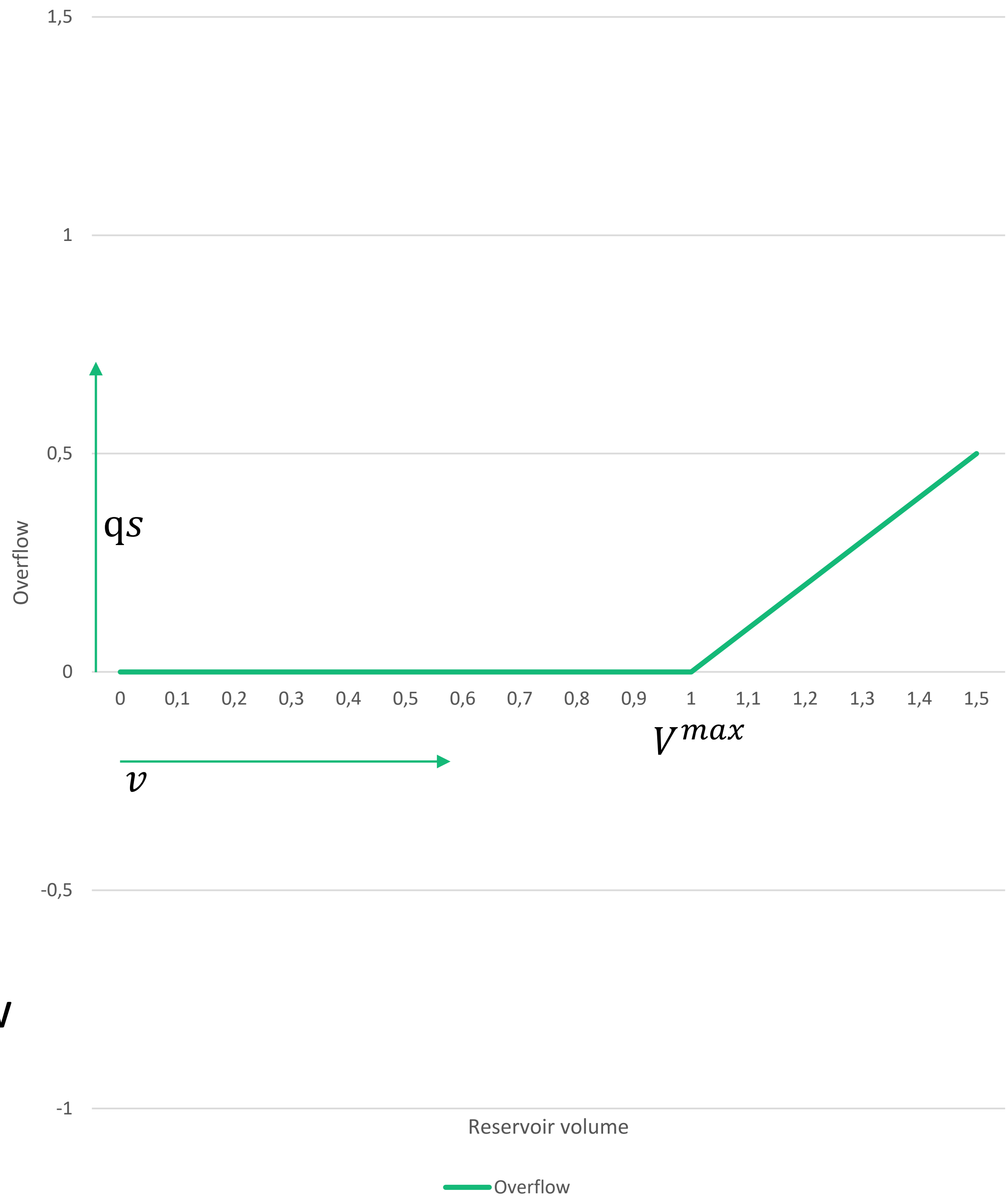
$$vs \leq v - V^{max} \cdot \delta$$

$$vs \leq M \cdot \delta$$

$$qs = c \cdot vs$$

$\delta = 0$ – no overflow

$\delta = 1$ – overflow



Zero bound

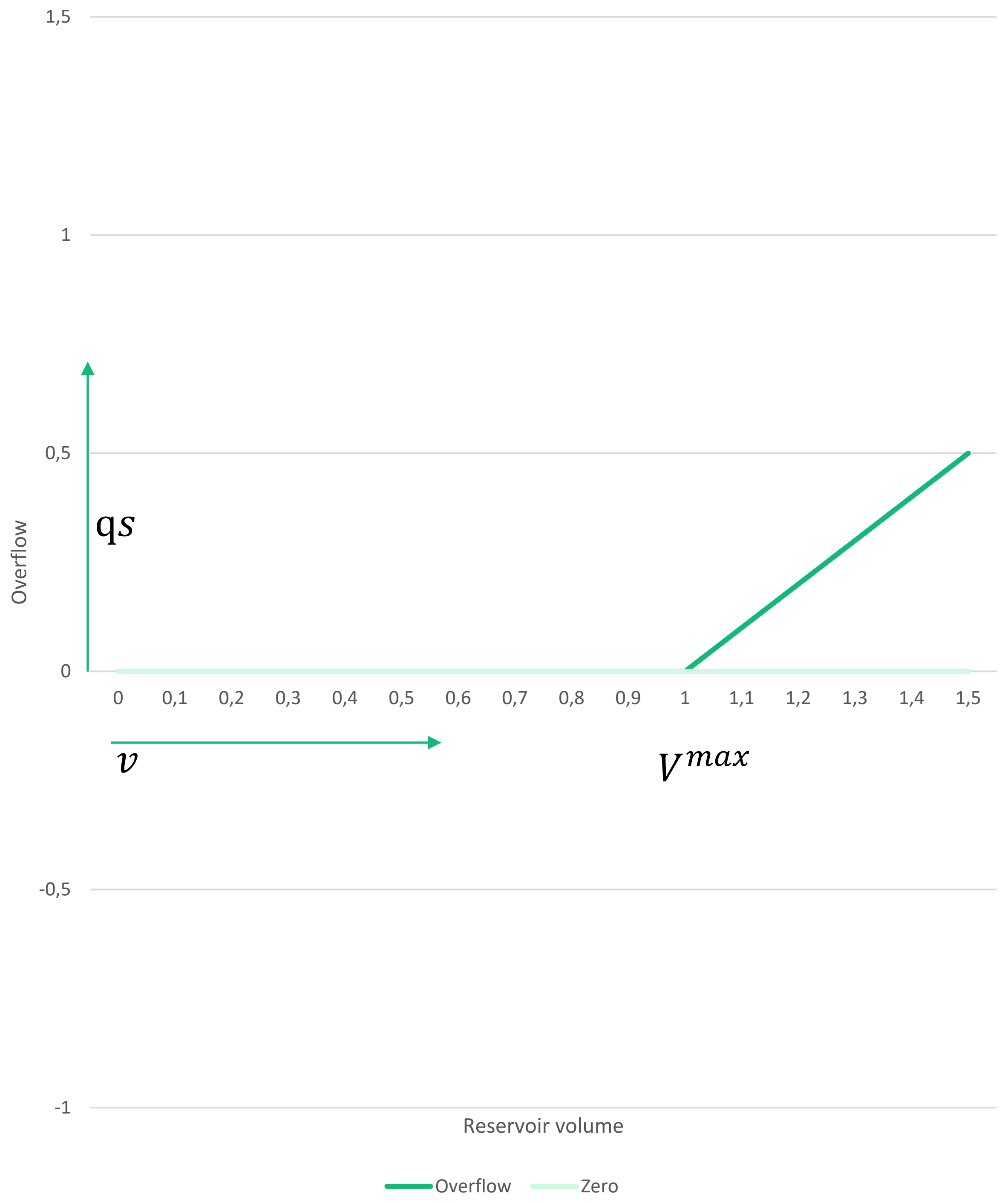
$$vs \geq 0$$

$$vs \geq v - V^{max}$$

$$vs \leq v - V^{max} \cdot \delta$$

$$vs \leq M \cdot \delta$$

$$qs = c \cdot vs$$



Upper and lower bounds

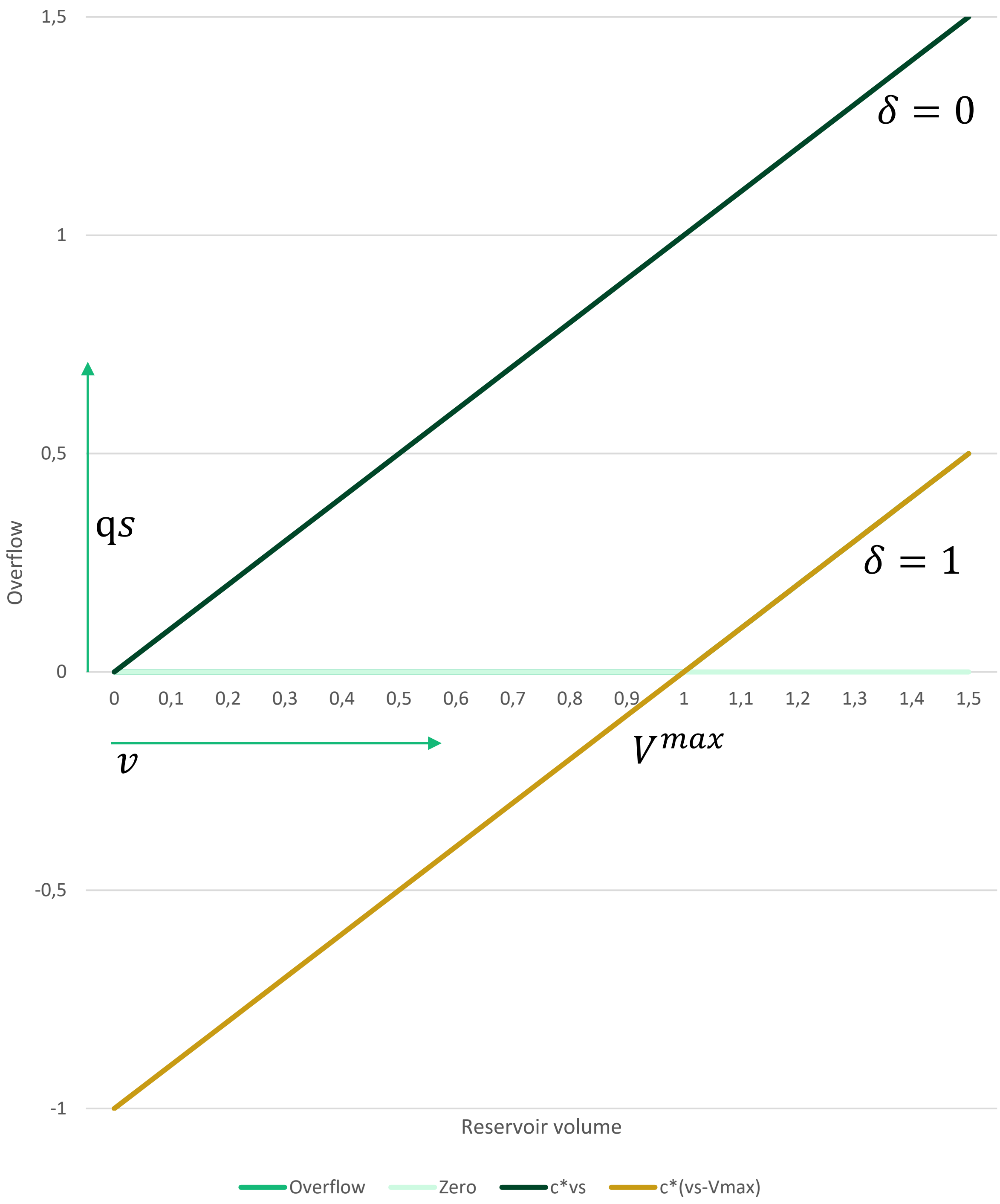
$$vs \geq 0$$

$$vs \geq v - V^{max}$$

$$vs \leq v - V^{max} \cdot \delta$$

$$vs \leq M \cdot \delta$$

$$qs = c \cdot vs$$



Big M

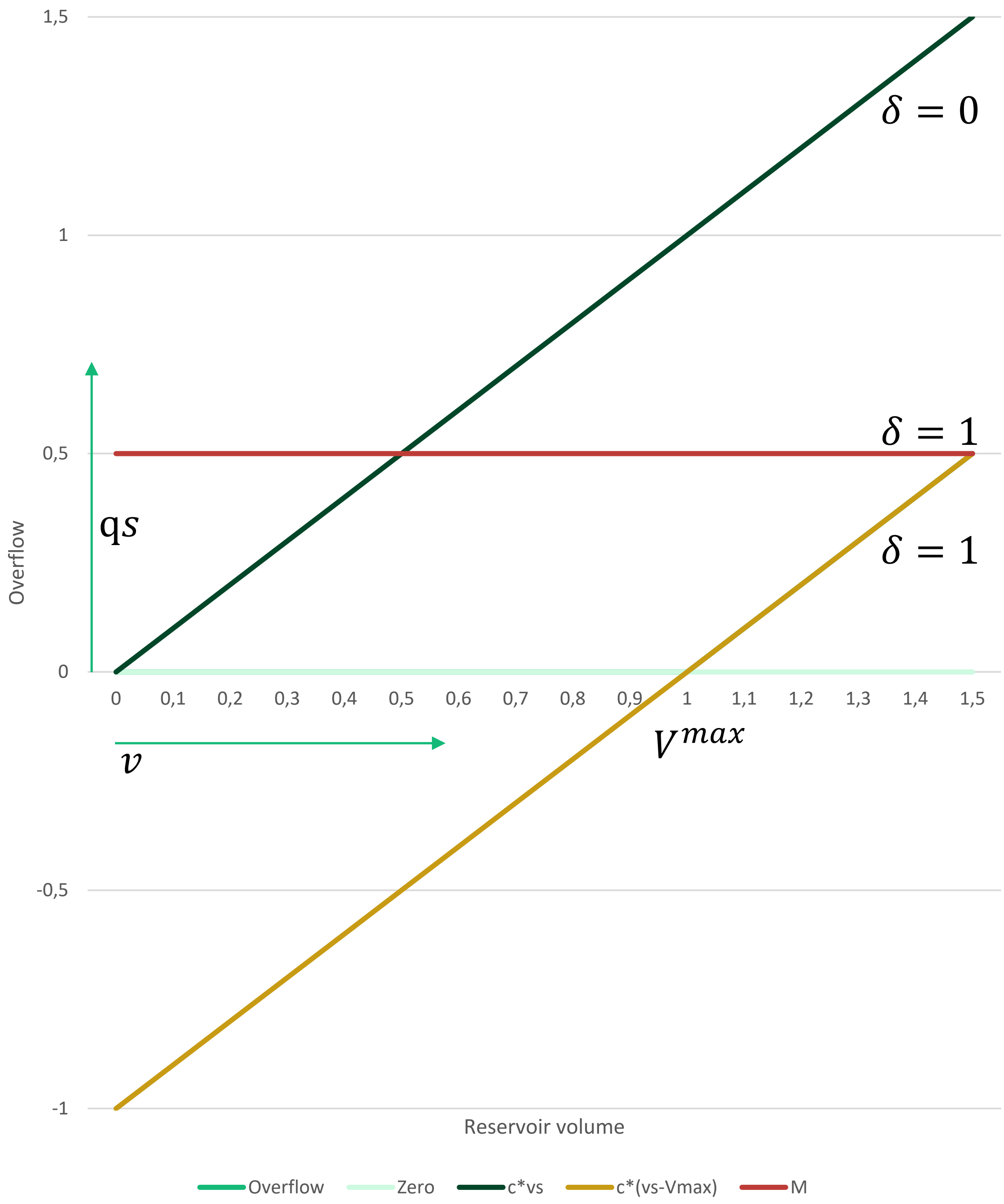
$$vs \geq 0$$

$$vs \geq v - V^{max}$$

$$vs \leq v - V^{max} \cdot \delta$$

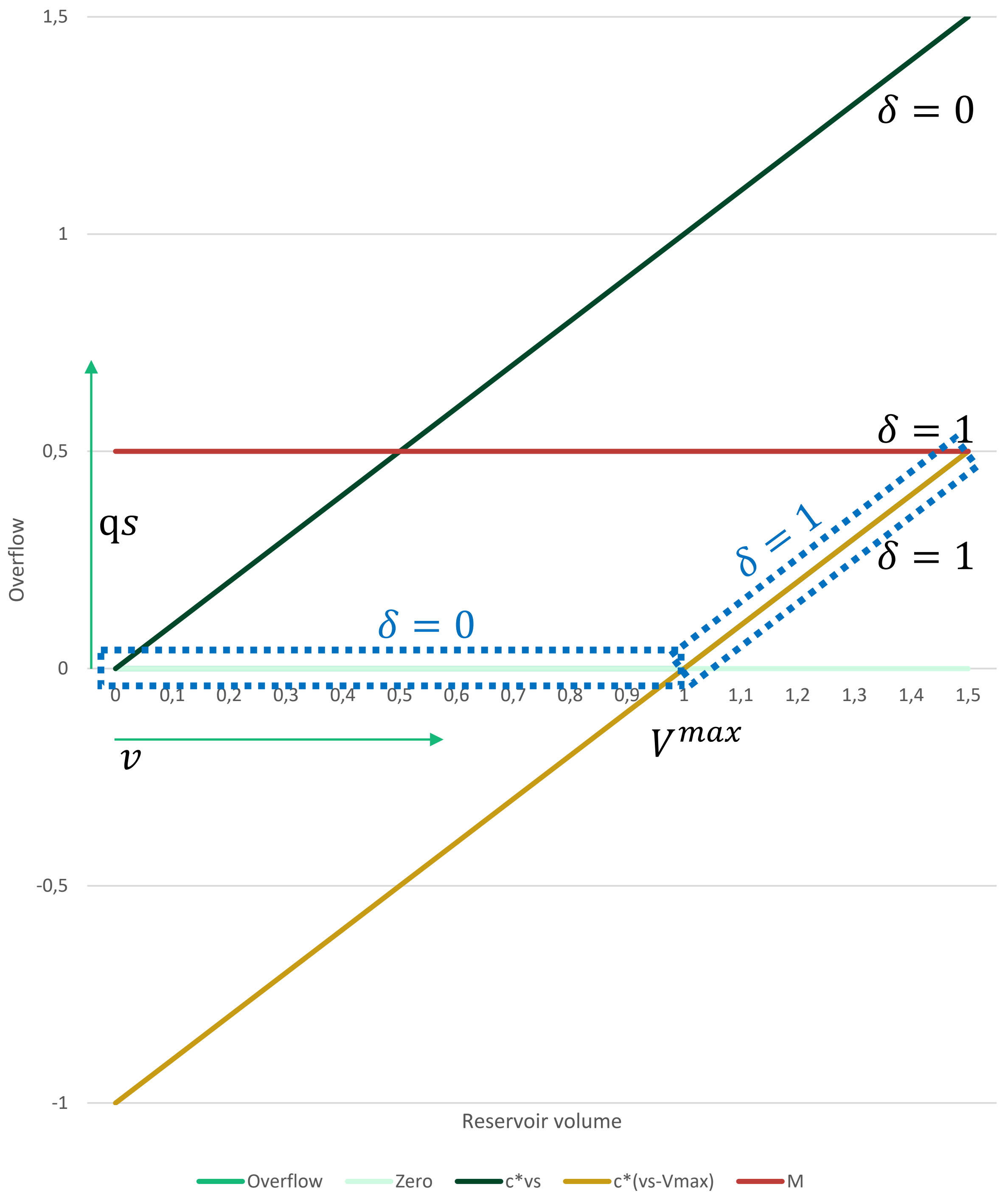
$$vs \leq M \cdot \delta$$

$$qs = c \cdot vs$$



Binary delta

$$vs \geq 0$$
$$vs \geq v - V^{max}$$
$$vs \leq v - V^{max} \cdot \delta$$
$$vs \leq M \cdot \delta$$
$$qs = c \cdot vs$$



Continuous delta

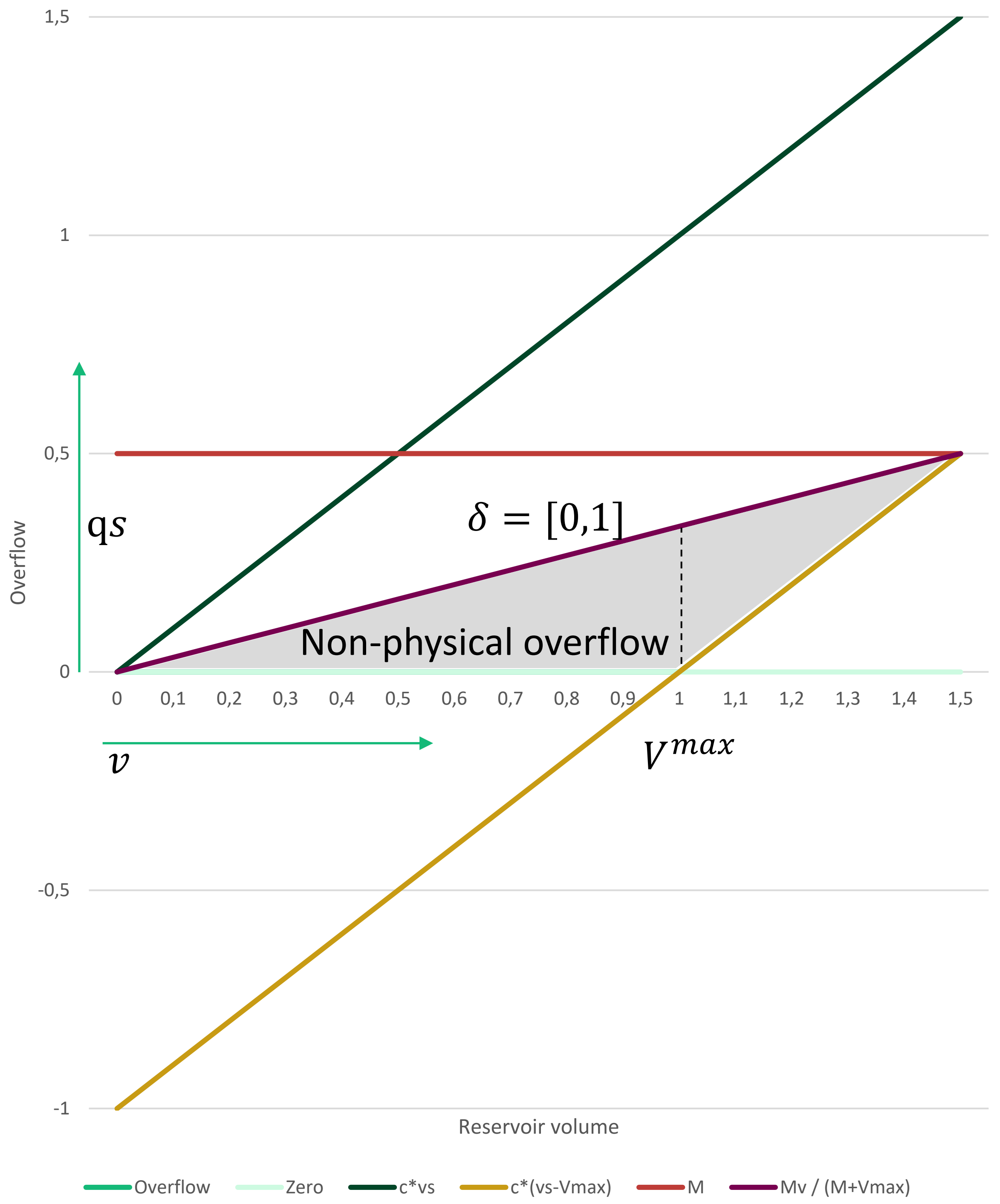
$$vs \geq 0$$

$$vs \geq v - V^{max}$$

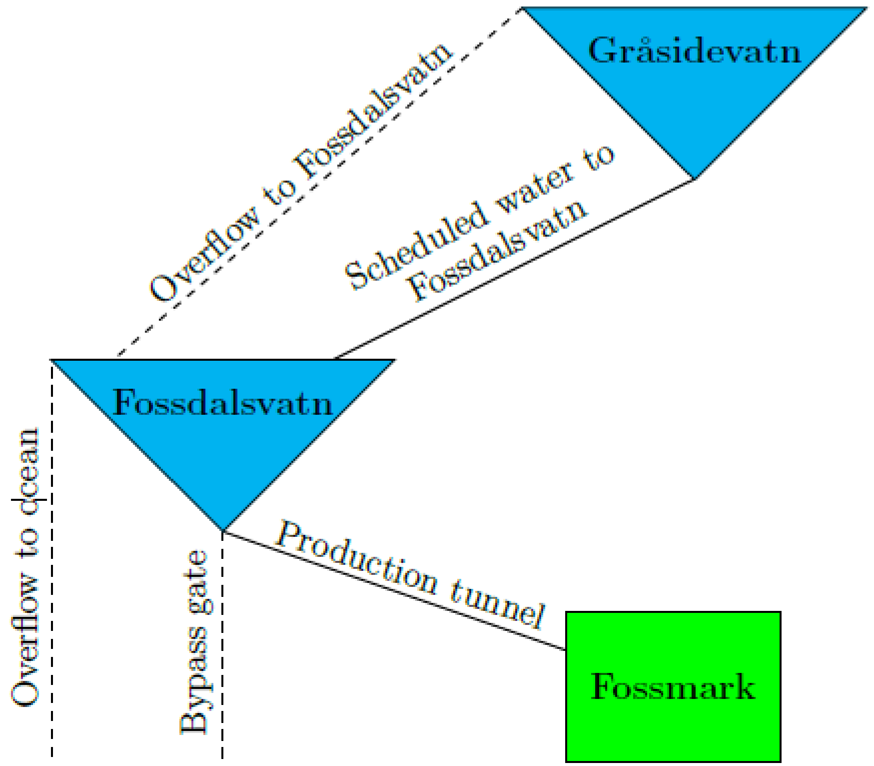
$$vs \leq v - V^{max} \cdot \delta$$

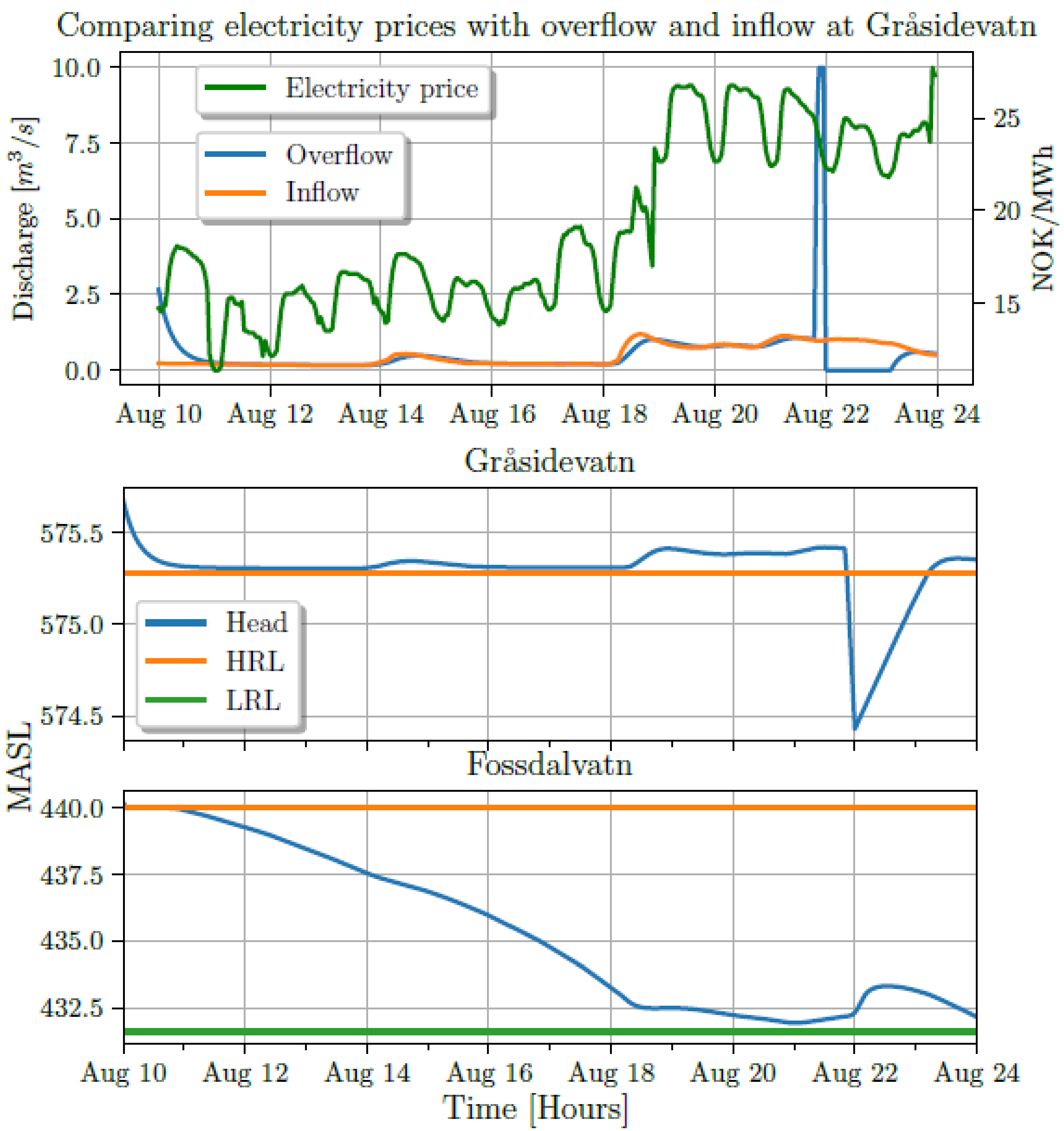
$$vs \leq M \cdot \delta$$

$$qs = c \cdot vs$$



Fossdal watercourse

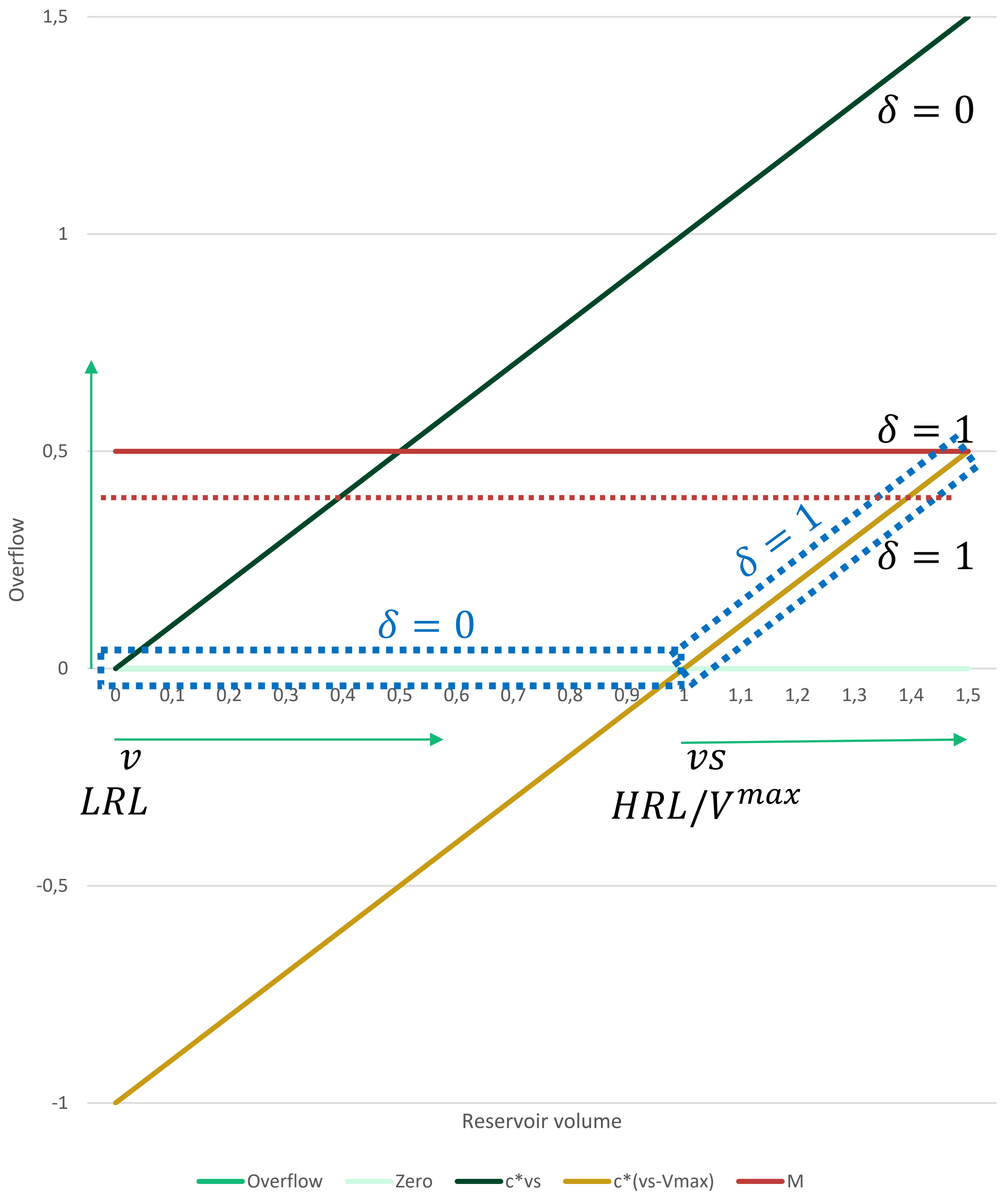




Comparing electricity prices with overflow and inflow at Gråsidevatn
Electricity price
Overflow
Inflow
Discharge [m^3/s]
NOK/MWh
10.0
7.5
5.0
2.5
0.0
25
20
15
Aug 10
Aug 12
Aug 14
Aug 16
Aug 18
Aug 20
Aug 22
Aug 24
Gråsidevatn
Head
HRL
LRL
575.5
575.0
574.5
MASL
Fossdalvatn
440.0
437.5
435.0
432.5
Aug 10
Aug 12
Aug 14
Aug 16
Aug 18
Aug 20
Aug 22
Aug 24
Time [Hours]

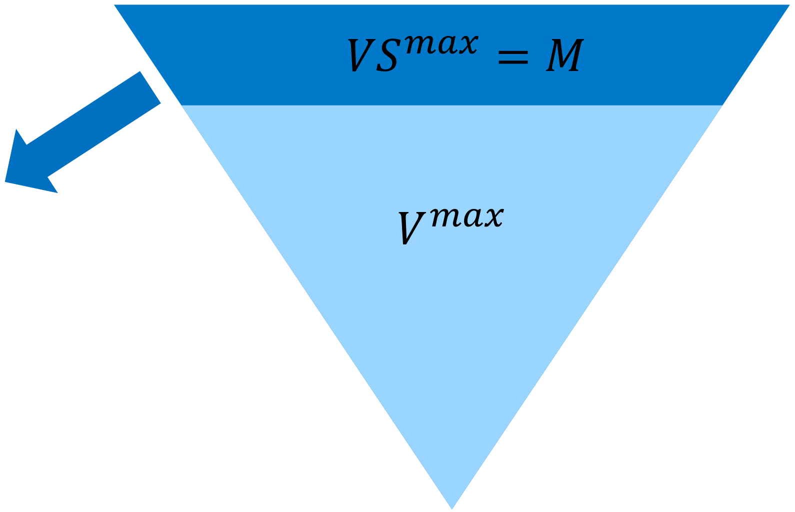
Binary delta

$$vs \geq 0$$
$$vs \geq v - V^{max}$$
$$vs \leq v - V^{max} \cdot \delta$$
$$vs \leq M \cdot \delta$$
$$qs = c \cdot vs$$



Big M

- The tightest big M is given by the maximum possible overflow volume.
- Can be approximated with known inflow by assuming the worst possible upstream production and gate discharge.
- Can be updated between the SLP iteration.



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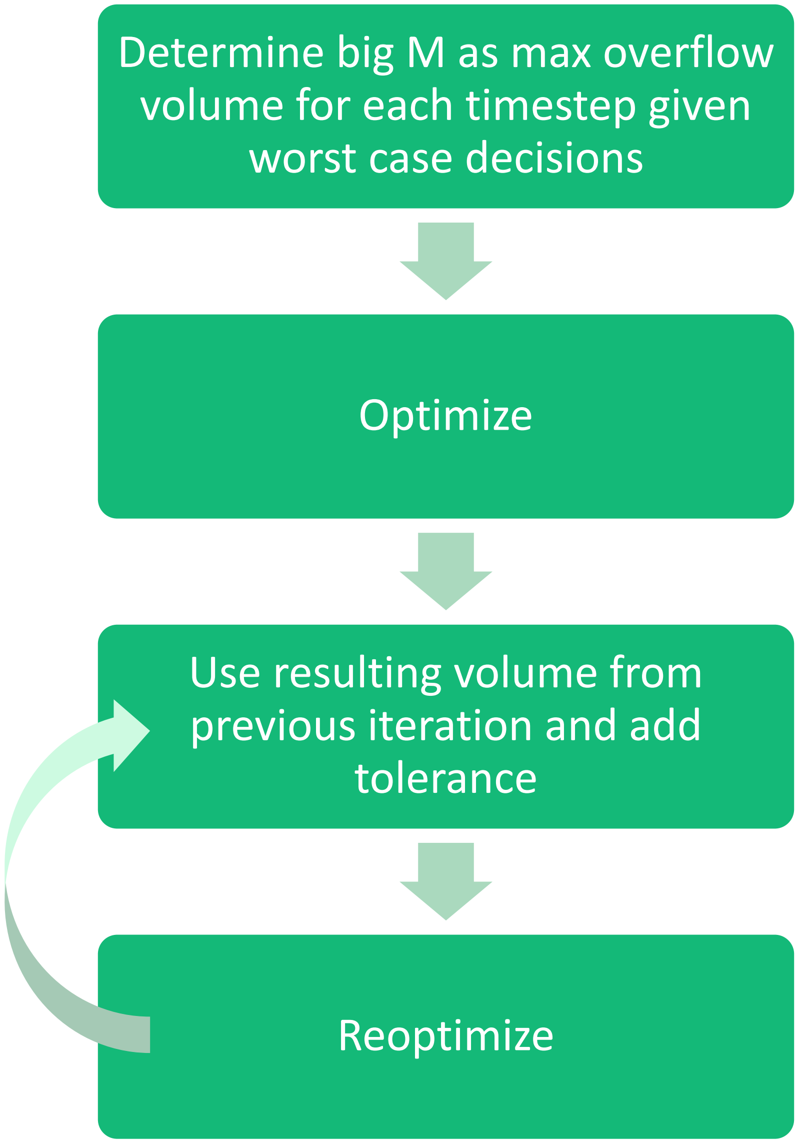
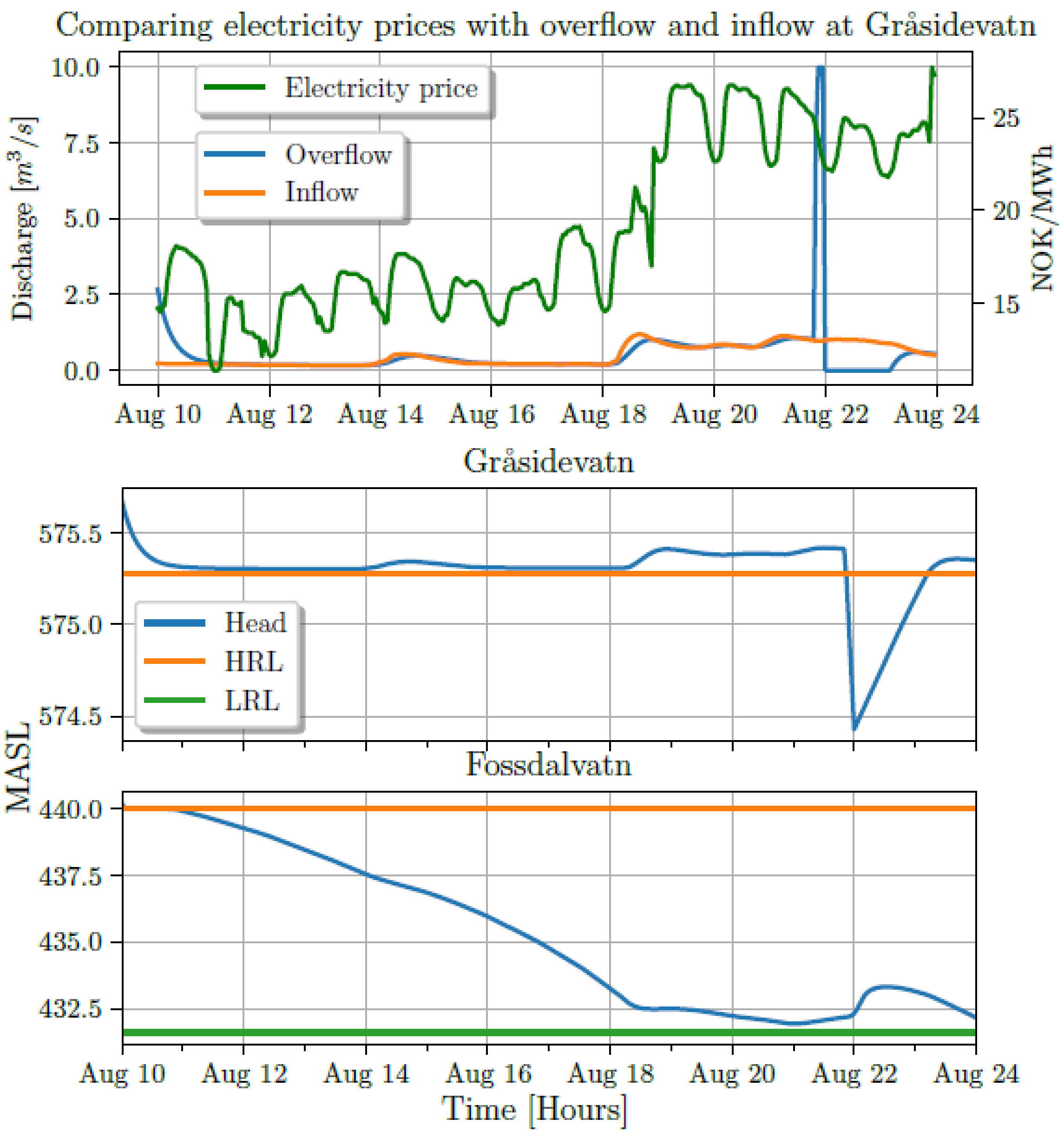
Big M heuristics for SLP (successive linear programming)

- Starting volume
- Inflow
- Overflow description
- Plant and gate discharge



SHOP

- SHOP is a short-term hydro scheduling model developed by SINTEF.
- Uses successive linear programming.
- In operational use by most of the major hydro power producers in the Nordic countries.


Comparing electricity prices with overflow and inflow at Gråsidevatn
Electricity price
Overflow
Inflow
Discharge [m^3/s]
NOK/MWh
10.0
7.5
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25
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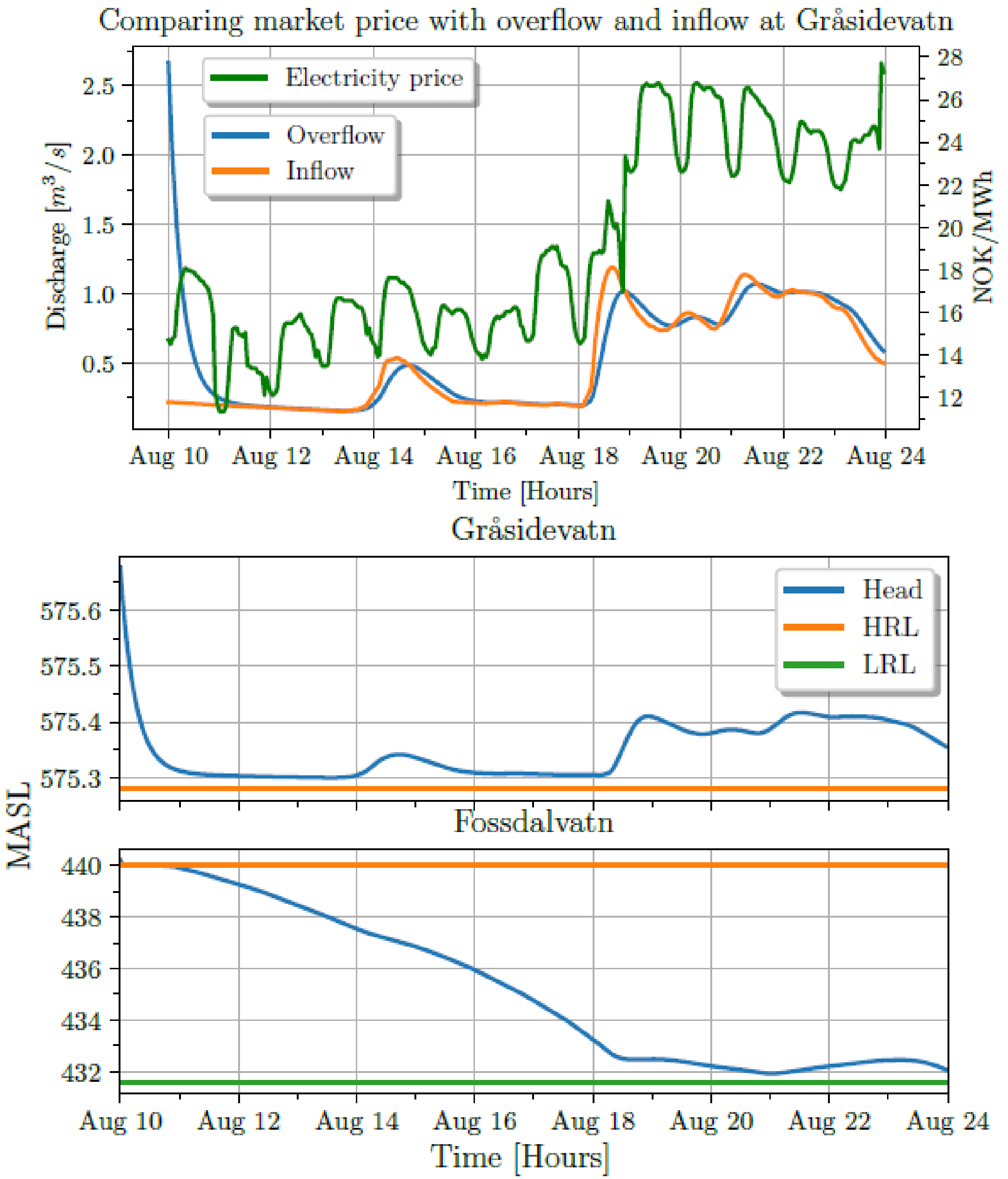
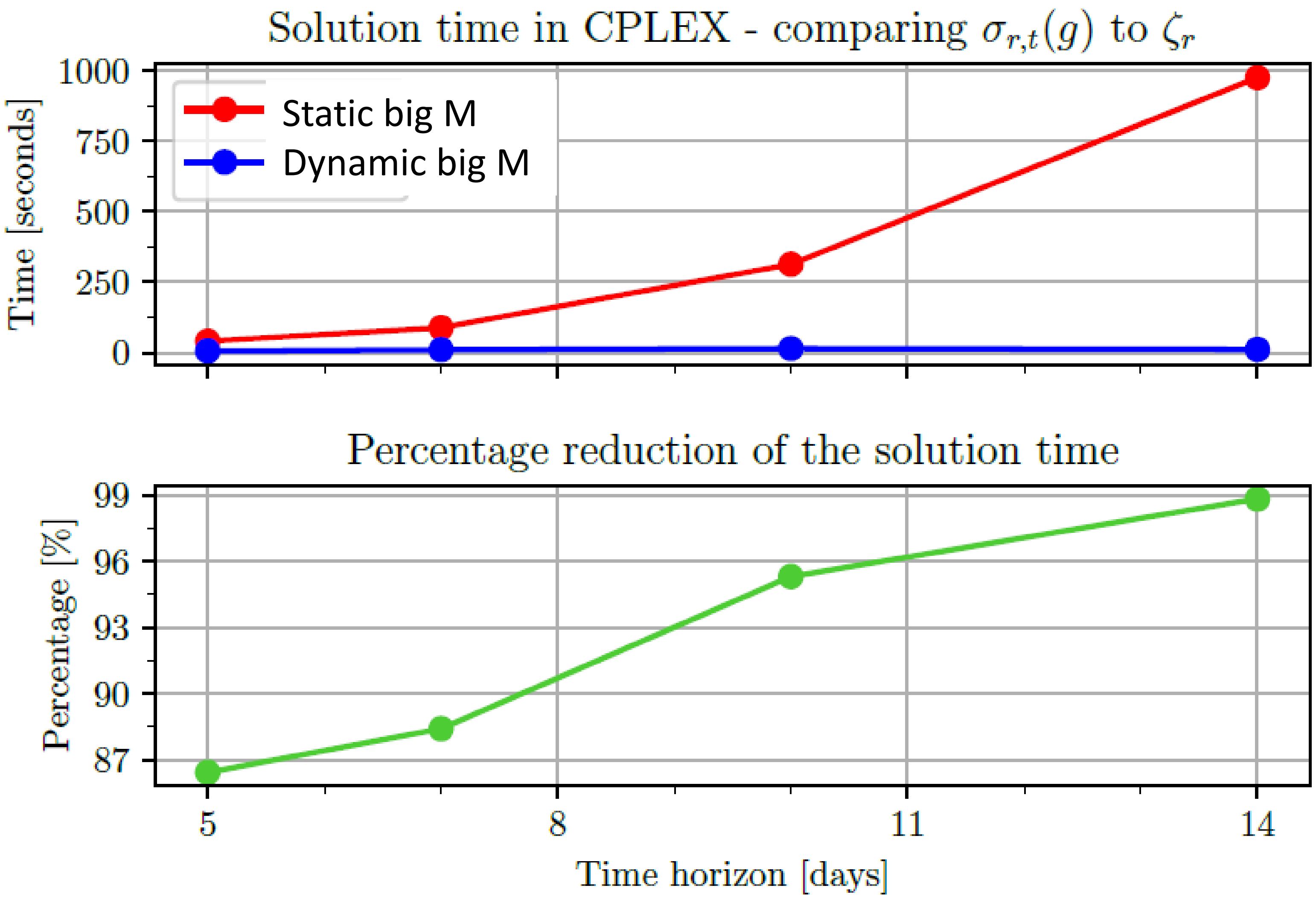
Time [Hours]


Comparing market price with overflow and inflow at Gråsidevatn
Electricity price
Overflow
Inflow
Discharge [m^3/s]
NOK/MWh
2.5
2.0
1.5
1.0
0.5
28
26
24
22
20
18
16
14
12
Aug 10
Aug 12
Aug 14
Aug 16
Aug 18
Aug 20
Aug 22
Aug 24
Time [Hours]
Gråsidevatn
Head
HRL
LRL
575.6
575.5
575.4
575.3
MASL
Fossdalvatn
440
438
436
434
432
Time [Hours]

Comparison of static and dynamic big M



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Optimizing big M?

Maximize flood volume

~~Minimize costs~~

Subject to physical and market constraints

Further work

- Investigate feasible directions towards tight feasible big M values.
- Test method for more complex systems and improve heuristics if necessary.
- Test other reasons for non-physical overflow.

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